WEST Search History

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DATE: Wednesday, September 22, 2004

Hide?	Set Name	Query	Hit Count
		DB=PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD; PLUR=YES; OP=ADJ	
☐	L19	L18 and ((magnetic adj resonance) or MRI or NMR)	2
☐	L18	L17 and (gradient)	7
☐	L17	L16 and (noncryogen$2 or non-cryogen$2 or (cryogen$2 with (free or "without" or "no")))	13
☐	L16	L15 and ((heat$4 or thermal$3 or temperature) with (reservoir or container or vessel or holder or receptacle or chamber))	35
☐	L15	L7 and (enthalpy)	36
☐	L14	L13 and ((magnetic adj resonance) or MRI or NMR)	11
☐	L13	L12 and (shield$4 or cage or Faraday or shim$4)	14
☐	L12	L11 and (noncryogen$2 or non-cryogen$2 or (cryogen$2 with (free or "without" or "no")))	21
☐	L11	L10 and (vacuum or chamber)	66
☐	L10	L9 and ((superconduct$4 or super-conduct$4 or "super conduct$4") with (magnet))	75
☐	L9	L8 and (magnet)	95
☐	L8	L7 and (cryocooler or cooler or "cryo" or cryo-cooler or cryostat$4 or cryostatically)	158
☐	L7	L6 and (pipe or tube or tubing or conduit or connector or connecter or copper or "Cu")	363
☐	L6	L5 and (mass or weight$4 or "kg" or kilogram)	379
☐	L5	L4 and (epoxy or ice or methacrylate or polyurethane or synthetic or rubber$4 or natural or plastic or resin or lead or "Pb")	530
☐	L4	L3 and (reservoir or container or vessel or holder or receptacle)	691
☐	L3	L2 and ((heat$4 or thermal$3 or temperature) with capacity)	1496
☐	L2	L1 and (heat$4 or thermal$3 or temperature)	44480
☐	L1	(superconduct$4 or super-conduct$4 or "super conduct$4")	76054

END OF SEARCH HISTORY

Hit List

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Search Results - Record(s) 1 through 11 of 11 returned.

☐ 1. Document ID: US 20040066193 A1

Using default format because multiple data bases are involved.

L14: Entry 1 of 11 File: PGPB Apr 8, 2004

PGPUB-DOCUMENT-NUMBER: 20040066193
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20040066193 A1

TITLE: Methods and devices for dissolving hyperpolarised solid material for nmr analyses

PUBLICATION-DATE: April 8, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY	RULE-47
Ardenkjaer-Larsen, Jan Henrik	Malmo		SE	
Axelsson, Oskar H.E.	Malmo		SE	
Golman, Klaes Koppel	Malmo		SE	
Hansson, Georg	Malmo		SE	
Johannesson, H.	Malmo		SE	
Servin, Rolf	Malmo		SE	
Thaning, Mikkel	Malmo		SE	
Hansson, Lennart	Malmo		SE	

US-CL-CURRENT: 324/309

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw. De

☐ 2. Document ID: US 5379600 A

L14: Entry 2 of 11 File: USPT Jan 10, 1995

US-PAT-NO: 5379600
DOCUMENT-IDENTIFIER: US 5379600 A

TITLE: Superconducting magnet and method for assembling the same

DATE-ISSUED: January 10, 1995

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY

Moritsu; Kazuki	Ako	JP
Matsumoto; Takahiro	Ako	JP
Horikawa; Mitsuo	Ako	JP
Nakagawa; Shuichi	Ako	JP
Yoshimura; Hideto	Amagasaki	JP
Nagao; Masashi	Amagasaki	JP
Inaguchi; Takashi	Amagasaki	JP

US-CL-CURRENT: 62/47.1; 505/892, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw. D

3. Document ID: US 5278502 A

L14: Entry 3 of 11 File: USPT Jan 11, 1994

US-PAT-NO: 5278502
DOCUMENT-IDENTIFIER: US 5278502 A

TITLE: Refrigerated superconducting MR magnet with integrated cryogenic gradient coils

DATE-ISSUED: January 11, 1994

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Laskaris; Evangelos T.	Schenectady	NY		
Dorri; Bizhan	Clifton Park	NY		
Vermilyea; Mark E.	Schenectady	NY		
Mueller; Otward M.	Ballston Lake	NY		

US-CL-CURRENT: 324/318; 324/319

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw. D

4. Document ID: US 5113165 A

L14: Entry 4 of 11 File: USPT May 12, 1992

US-PAT-NO: 5113165
DOCUMENT-IDENTIFIER: US 5113165 A

TITLE: Superconductive magnet with thermal diode

DATE-ISSUED: May 12, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ackermann; Robert A.	Schenectady	NY		

US-CL-CURRENT: 335/216; 335/299, 335/300, 335/301, 505/879, 62/45.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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5. Document ID: US RE33878 E

L14: Entry 5 of 11 File: USPT Apr 14, 1992

US-PAT-NO: RE33878
DOCUMENT-IDENTIFIER: US RE33878 E

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: April 14, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Boxborough	MA		
Lessard; Philip A.	Boxborough	MA		

US-CL-CURRENT: 62/47.1; 165/133, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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6. Document ID: US 5093645 A

L14: Entry 6 of 11 File: USPT Mar 3, 1992

US-PAT-NO: 5093645
DOCUMENT-IDENTIFIER: US 5093645 A

TITLE: Superconductive switch for conduction cooled superconductive magnet

DATE-ISSUED: March 3, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Dorri; Bizhan	Clifton Park	NY		
Laskaris; Evangelos T.	Schenectady	NY		

US-CL-CURRENT: 335/216; 174/125.1, 338/325

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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7. Document ID: US 4935714 A

L14: Entry 7 of 11 File: USPT Jun 19, 1990

US-PAT-NO: 4935714
DOCUMENT-IDENTIFIER: US 4935714 A

TITLE: Low thermal conductance support for a radiation shield in a MR magnet

DATE-ISSUED: June 19, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Vermilyea; Mark E.	Schenectady	NY		

US-CL-CURRENT: 505/211; 324/318, 335/216, 335/299

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

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8. Document ID: US 4924198 A

L14: Entry 8 of 11 File: USPT May 8, 1990

US-PAT-NO: 4924198
DOCUMENT-IDENTIFIER: US 4924198 A

TITLE: Superconductive magnetic resonance magnet without cryogens

DATE-ISSUED: May 8, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Laskaris; Evangelos T.	Schenectady	NY		

US-CL-CURRENT: 505/211; 174/15.4, 324/318, 335/216, 335/299, 505/163

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

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9. Document ID: US 4902995 A

L14: Entry 9 of 11 File: USPT Feb 20, 1990

US-PAT-NO: 4902995
DOCUMENT-IDENTIFIER: US 4902995 A

TITLE: Cable suspension system for cylindrical cryogenic vessels

DATE-ISSUED: February 20, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Vermilyea; Mark E.	Schenectady	NY		

US-CL-CURRENT: 505/211; 174/15.4, 324/318, 335/216, 335/299

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

10. Document ID: US 4895831 A

L14: Entry 10 of 11 File: USPT Jan 23, 1990

US-PAT-NO: 4895831
DOCUMENT-IDENTIFIER: US 4895831 A

TITLE: Ceramic superconductor cryogenic current lead

DATE-ISSUED: January 23, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Laskaris; Evangelos T.	Schenectady	NY		

US-CL-CURRENT: 505/163; 174/15.5, 335/299, 335/300, 505/211, 505/886

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

11. Document ID: US 4766741 A

L14: Entry 11 of 11 File: USPT Aug 30, 1988

US-PAT-NO: 4766741
DOCUMENT-IDENTIFIER: US 4766741 A

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: August 30, 1988

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Acton	MA		
Lessard; Philip A.	Acton	MA		

US-CL-CURRENT: 62/51.2; 165/133, 62/47.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

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Term	Documents
MAGNETIC	1427723

MAGNETICS	12351
RESONANCE	280011
RESONANCES	16254
MRI	24243
MRIS	329
NMR	137006
NMRS	235
(13 AND (MRI OR (MAGNETIC ADJ RESONANCE) OR NMR)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	11
(L13 AND ((MAGNETIC ADJ RESONANCE) OR MRI OR NMR)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	11

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L14: Entry 3 of 11 File: USPT Jan 11, 1994

DOCUMENT-IDENTIFIER: US 5278502 A
TITLE: Refrigerated superconducting MR magnet with integrated cryogenic gradient coils

Abstract Text (1):
This invention relates to refrigerated superconducting MR magnets having integrated cryogenic gradient coils. In particular, the amount of eddy currents produced by the magnet are substantially reduced while reducing the size and weight, and, therefore, the cost of the superconducting magnet required to produce an acceptable MR image.

Brief Summary Text (2):
This application is related to commonly assigned U.S. patent applications Ser. Nos. 759,337, 759,389 and 759,336, entitled "Refrigerated Superconducting MR Magnet with Integrated Gradient Coils"; "Eddy Current Free MRI Magnet With Integrated Gradient Coils"; and "Demountable Conduction Cooled Current Leads For Refrigerated Superconducting Magnets", respectively.

Brief Summary Text (5):
This invention relates to refrigerated superconducting MR magnets having integrated cryogenic gradient coils. Such structures of this type generally reduce the size and weight and therefore, the cost of the superconducting magnet required for an MR imaging system while substantially eliminating the resultant eddy currents produced in the magnet.

Brief Summary Text (7):
Present superconducting MR magnets employ windings which operate in liquid helium to maintain the temperature at approximately 4 K. The liquid helium pool requires a vessel which is vacuum tight and which meets ASME pressure vessel requirements; such a vessel is typically made of welded aluminum alloy cylinders and flanges. Thermal radiation shields, of which two are typically used, are also made of welded aluminum pieces and contain the helium vessel. When the gradient coils are pulsed in the bore of the magnet, the resulting time changing magnetic flux in any of the electrically conducting cylinders sets up eddy currents which, in turn, produce other magnetic fields which degrade the quality of the desired gradient field in space and time. This behavior makes it attractive for the aggressive pulse sequences which are routinely used in MR imaging today to use a second set of gradient coils in the magnet bore. This shield gradient coil sets up fields which counteract those of the main gradient coil radially outside of the shield coil, thus greatly reducing any mutual inductance with conducting members such as the thermal shields and minimizing the resultant eddy currents.

Brief Summary Text (8):
The use of such shield gradient coils increases the radial thickness of the gradient coil set relative to a simple single coil set because of the required gap between them and dictates the size, and thus weight and cost, of a conventional magnet, which normally lies radially outside of the shield gradient. Therefore, a more advantageous system, then, would be realized if the magnet could be made to have no mutual coupling to the gradient coil set and if it could be placed in much closer proximity to the gradients without having any deleterious eddy currents

induced in it. The resulting system could be dramatically smaller and less expensive than existing ones.

Brief Summary Text (9):
It is apparent from the above that there exists a need in the art for a refrigerated superconducting MR magnet which is reduced in size, weight and cost through simplicity of parts and uniqueness of structure, and which at least equals the imaging characteristics of known superconducting magnets, but which at the same time substantially reduces the amounts of resultant eddy currents produced in the magnet by the gradient coils. It is a purpose of this invention to fulfill this and other needs in the art in a manner more apparent to the skilled artisan once given the following disclosure.

Brief Summary Text (11):
Generally speaking, this invention fulfills these needs by providing a refrigerated MR imaging magnet for reducing eddy currents, comprising at least two gradient coil/thermal shield means located at a predetermined distance away from each other, a magnet cartridge means having a coil form means and a main coil means wound on said coil form means and substantially located radially between said gradient coil/thermal shield means, a support means for said gradient coil/thermal shield means and said magnet cartridge means, a vacuum bore tube means, a RF shield means rigidly attached to said bore tube means, a passive shim means substantially located adjacent to said bore means, a RF coil means located at a predetermined distance away from said bore tube means, and a vacuum enclosure means which includes said vacuum bore tube means and which substantially encloses said gradient coil/thermal shield means and said magnet cartridge means.

Brief Summary Text (12):
In certain preferred embodiments, the gradient coil/thermal shield means acts as a thermal radiation shield and as a gradient coil for the system. Also, the gradient coil/thermal shields and magnet cartridge are supported within the enclosure by independent sets of mechanical supports to reduce vibration of the magnet cartridge when the gradient coils are electrically pulsed. In addition, the magnet cartridge must be mechanically decoupled from the refrigerator cold head. Finally, both the main and shield gradient coils are layered with electrically decoupled strips of any high thermal conductivity material such as copper or aluminum in order to provide the required axial heat conduction to the refrigerator while reducing to a tolerable level the resultant eddy currents resulting from the electrical pulsation of the gradient coils.

Brief Summary Text (13):
In another further preferred embodiment, the size and weight and, ultimately, the cost of the MR imaging system is reduced when the superconducting magnet of the present invention is employed while substantially eliminating the eddy currents produced in the magnet by the electrical pulsation of the gradient coils.

Brief Summary Text (14):
The preferred superconducting MR magnet, according to this invention, offers the following features: lightness in weight; good superconducting characteristics; good MR imaging characteristics; good stability; substantially reduced resultant eddy currents; good durability; improved economy; and high strength for safety. In fact, in many of the preferred embodiments, these factors of weight, eddy currents and economy are optimized to an extent considerably higher than heretofore achieved in prior, known superconducting MR magnets.

Drawing Description Text (3):
FIG. 1 is a side plan view of a refrigerated superconducting MR magnet with integrated cryogenic gradient coils, according to the present invention;

Drawing Description Text (5):

FIG. 3 is a detailed, end plan view drawing illustrating the connection between the shield gradient coil, the main coil form, and the mechanical supports taken along line 3--3 in FIG. 1, according to the present invention; and

Drawing Description Text (6):
FIG. 4 is a schematic drawing depicting the locations of the mechanical supports with respect to the shield gradient coil and the main coil form, according to the present invention.

Detailed Description Text (2):
With reference first to FIG. 1, there is illustrated a refrigerated superconducting, integrated cryogenic gradient coil MR magnet 2. Basically, magnet 2 includes vacuum vessel cylinder 4, supports 6, 10, vacuum enclosure bore tube 24, shield gradient coil/outer thermal shield assembly 8, magnet cartridge 12, coil form 13, coils 14, 16, 18, 20, main gradient coil/inner thermal shield assembly 22, RF coil 26, magnetic shield end plate 28, RF shield 29 and mechanical supports 78, 82, 84, 88.

Detailed Description Text (3):
With respect to FIG. 2, the elements found in FIG. 1, except mechanical supports 78,82,84 and 88, will be more specifically set forth. In particular, vacuum vessel 4 which, preferably, is constructed of any suitable ferromagnetic and impermeable material such as iron or carbon steel is rigidly attached to end plate 28 by a conventional fastener 30 and a conventional washer 32. End plate 28, preferably, is constructed of any suitable ferromagnetic and impermeable material such as iron or carbon steel. A conventional elastomeric o-ring 34 is placed in groove 35 in end plate 28. O-ring 34 prevents any leakage from the atmosphere into cavity 5 along the interface between vessel 4 and end plate 28.

Detailed Description Text (4):
Support 6, which preferably, is constructed of any suitable fiberglass material is rigidly held within clamp 42 which, in turn, is held together with conventional fasteners 44 and 46. Supports are located approximately 90.degree. from each other around the circumference of shield gradient coil outer thermal shield assembly 8. Clamp 42, preferably, is constructed of stainless steel and contains grooves 48 which mate with matching grooves in support 6 so that support 6 remains stationary within clamp 42. Clamp 42 is rigidly attached to end plate 28 by a conventional close tolerance fastener 36. The grooves in support 6 are constructed by conventional machining techniques. A cap 38 is placed over end plate 28 at the place where fastener 36 connects with end plate 28 and a vacuum tight weldment 40 is placed around cap 38 to provide a vacuum seal between cap 38 and end plate 28. Cap 38 and weldment 40 are used to substantially eliminate any leakage from the atmosphere to cavity 5 along fastener 36.

Detailed Description Text (5):
Located below support 6 is shield gradient coil/outer thermal shield assembly 8, hereinafter referred to as assembly 8. Assembly 8, preferably, is constructed substantially the same as the gradient coil set forth in U.S. Pat. No. 4,737,716 to Roemer et al., entitled "Self-Shielded Gradient Coils for Nuclear Magnetic Resonance Imaging" and assigned to the same assignee as the present invention. In order to assume the proper thermal shielding and to substantially eliminate eddy currents induced from the pulsation of the gradient coil, the conductive part of assembly 8 is electrically segmented in the circumferential direction. In particular, overlapping axial straps 90 (FIG. 3) of any material with high thermal conductivity such as copper or aluminum are bonded by conventional bonding techniques to the inner or outer surface of assembly 8 and are electrically insulated from one another by insulators 92, preferably, a film insulation such as Mylar polyethylene terephthalate film. Straps 90 provide good axial thermal conduction. Insulators 92 are either applied directly to each strap 90 or are inserted at the overlapping interface between each strap 90 during assembly.

Coil/shield assembly 8 is rigidly attached to end flange 52 by fastener 50 with an indium interface material to form a high thermal conductivity joint. End flange 52, preferably, is constructed of copper. Coil/shield 8 is also rigidly attached to support 6 by mechanical supports 78,82 (FIGS. 1 and 3). The suspension system for coil/shield assembly consisting of coil/shields 8 and 22 and end flanges 52 is designed to transmit vibration from the coil/shield assembly to the vacuum vessel 4 to minimize vibration of magnet cartridge 12.

Detailed Description Text (6):
Thermal strap 80 which, preferably, is constructed of copper, thermally connects support 10 to coil/shield 8. Strap 80 is rigidly connected to coil/shield 8 by a high thermal conductivity joint 83. Strap 80 is rigidly connected to support 10 by a high thermal conductivity joint 79. Strap 80 provides a conduction path between coil/shield 8 and support 10 away from end plates 28 so that heat can be shunted to coil/shield 8 along strap 80 instead of being conducted along support 10 to magnet cartridge 12.

Detailed Description Text (7):
Magnet cartridge 12 consists of coil form 13, which, preferably, is constructed of any suitable fiberglass reinforced epoxy material, and coils 14, 16, 18, 20. The entire structure is epoxy impregnated for good thermal conductivity and high strength. Cartridge 12 is substantially constructed the same as winding 13 as set forth in U.S. Pat. No. 4,924,198 to E. T. Laskaris, entitled "Superconductive Magnet Resonance Magnet Without Cryogenes" and assigned to the same assignee as the present invention. Coils 14,16,18,20, preferably, are constructed of Nb.sub.3 Sn which are wound by conventional techniques on form 13. Cartridge 12 is rigidly secured to support 10 by mechanical supports 84,88 (FIG. 1). In this manner, the connections between cartridge 12, support 10 and mechanical supports 84,88 substantially reduce any vibrations created in cartridge 12 which, in turn, reduces the likelihood of image artifacts being created. Support 10 which, preferably, is constructed of any suitable fiberglass material is rigidly held within clamp 60 which, in turn is held together with conventional fasteners 62 and 64. Clamp 60, preferably, is constructed of stainless steel and contains grooves 66 which mate with the matching grooves in support 10 so that support 10 remains stationary within clamp 60. The grooves in clamp 60 and support 10 are constructed by conventional machining techniques. Clamp 60 is rigidly attached to end plate 28 by a conventional close tolerance fastener 54. Fastener 54 also passes through an opening 55 in end flange 52. A cap 56 is placed over end plate 28 at the place where fastener 54 connects with end plate 28 and a vacuum tight weldment 58 is placed around cap 56 provide a vacuum seal between cap 56 and end plate 28. Cap 56 and weldment 58 are used to substantially eliminate any leakage from the atmosphere to cavity 5 along fastener 54.

Detailed Description Text (8):
Located along the inner diameter of form 13 are strips 17 (FIG. 3). Strips 17, preferably, are constructed of copper or aluminum or any other high thermal conductivity material. Strips 17 are placed on form 13 in an overlapping fashion such that at the areas where the edges of strips 17 overlap, an insulation 19, such as Mylar polyethylene terephthalate film is placed between the overlapping areas so that strips 17 do not electrically contact each other. Insulation 19 can either be applied directly to strips 17 or placed between the areas where strips 17 overlap during assembly. Strips 17 provide axial heat conduction for cartridge 12 while minimizing eddy currents created in cartridge 12 which, in turn, reduces the likelihood of image artifacts being created.

Detailed Description Text (9):
Located radially inside of cartridge 12 is main gradient coil/thermal shield assembly 22, hereinafter referred to as coil/shield assembly 22. Assembly 22, is constructed in the same manner and with the same materials as coil/shield assembly 8 with the exception that the gradient windings are configured differently

according to conventional techniques as set forth in U.S. Pat. No. 4,737,716. Coil/shield assembly 22 is rigidly attached to end flange 52 by fastener 68 with an indium interface material to form a high thermal conductivity joint. A conventional RF shield 29 is rigidly attached to bore tube 24 by a conventional adhesive such that shield 29 is positioned axially within end plate 28. Bore tube 24 which, preferably, is constructed of a vacuum tight fiber-reinforced epoxy material is contained within end plates 28. A conventional, elastomeric o-ring 76 is located in a groove 77 in each end plate 28 so that there is substantially no leakage from the atmosphere along the interface between bore tube 24 and end plate 28 into cavity 5.

Detailed Description Text (10):
A conventional RF coil 26 is rigidly attached to extension 70 by a conventional fastener 74. Coil 26, preferably, is constructed of fiberglass reinforced epoxy and copper while extension 70 is constructed of stainless steel. Extension 70 is rigidly attached to end plate 28 by a conventional fastener 72.

Detailed Description Text (11):
It is to be understood that while less than one half of magnet 2 is depicted in FIG. 2, the magnet is symmetric about its axial midplane as evidenced by FIG. 1.

Detailed Description Text (12):
FIG. 3 more clearly illustrates the connections between coil/shield assembly 8 and support 6, and between coil form 13 and support 10, respectively. In particular, coil/shield assembly 8 is rigidly attached to support 6 by mechanical supports 78,82 and a conventional fastener 89. Mechanical supports 78,82, preferably, are constructed of a stainless steel which is non-magnetic in the temperature range of 10-40 K. Coil form 13 is rigidly attached to support 10 by mechanical supports 84,88 and conventional fasteners 86. Mechanical supports 84,88, preferably, are constructed of the same material as supports 78,82. As mentioned earlier, coil/shield assembly 8 and coil form 13 are attached to their respective mechanical supports in order to reduce vibrations of cartridge 12 induced by vibrations of gradient coils 8 and 22 which, in turn, improves the quality of the images produced by magnet 2.

Detailed Description Text (13):
FIG. 4 is a schematic representation of the orientation of supports 6 around coil/shield 8. In particular, supports 6, preferably, are located at approximately 90.degree. from each other around the circumference of coil/shield 8. Also depicted are mechanical supports 78 and fasteners 89. Supports 6 are positioned around coil/shield 8 in this manner in order to rigidly support the gradient coil assembly within the vessel 4.

Detailed Description Text (14):
Radially inward of bore 24 is a space for a passive shim set which includes axial rails 94, drawers 96 and conventional passive shims 98 (FIG. 3). In particular, rails 94 are bonded by conventional bonding techniques to the inner radial surface of bore 24 to provide support for drawers 96. Drawers 96, preferably, are constructed of fiberglass and are used to carry passive shims 98.

Detailed Description Text (15):
In order to properly refrigerate the components of magnet 2, a conventional Gifford-McMahon cryocooler is rigidly attached to magnet 2 by conventional high thermal conductivity joints. In particular, one end flange 52 and magnet cartridge 12 are thermally connected by the high thermal conductivity joints to the first and second stages of the cryocooler, respectively. Typically, magnet cartridge 12 is maintained at approximately 10 K. while coil/shields 8 and 22, via end flange 52, are maintained at approximately 50 K. Because of the limited capacity of commercially available Gifford-McMahon refrigerators, the current leads which power the main coils should be demountable once the coil is placed in persistent mode so

that when the gradient coils are pulsed their additional heat load to the refrigerator can be removed. The operating temperature of the refrigerator is determined by its heat load. Since the resistivity of the copper conductors used for the gradient windings, and hence their resistive heating at a given current, is temperature dependent around 50 K, the exact operating temperature cannot be determined a priori. An estimate of the heat inputs (in Watts) to the first stage of the refrigerator for a typical 0.5T magnet system using Signa-type gradient coils is set forth below in Example 1. The generation is based on a set of gradient windings designed using the standing design tools to fit in the prototype magnet and operated at an rms current of 25 A (peak of 84 A) for a typical imaging pulse sequence.

Detailed Description Text (17):
The refrigerator chosen must be capable of removing this much heat at its first stage while maintaining a temperature of 50 K.; such a machine is available from Leybold-Heraeus. Note that the heat input from a dual cryocooler interface is accounted for; such a device is useful from a standpoint of increasing the reliability of the system. Note also that the conduction down the main coil power leads, 14% of the total, can be eliminated if the magnet can be made to operate in the persistent mode and a set of retractable conduction cooled leads is implemented for the magnet leads as set forth in U.S. patent application Ser. No. 07/759,336. Such an improvement would lead to a lower operating temperature for the gradient coils, therefore lower heat generation and improved second stage capacity or reduced second stage temperature as the refrigerator load map shows a temperature increase at the second stage with increased first stage heat load.

Detailed Description Text (18):
Magnet 2 is an improvement over prior, refrigerated superconducting MR magnets for several reasons. First, because magnet cartridge 12 is positioned between the inner and outer gradient coils 22 and 8, respectively, its size and therefore, the size of vessel 4 are substantially reduced which reduces the weight and the cost of magnet 2. Second, due to the fact that coil/shield assemblies 8,22 and magnet cartridge 12 have been relocated, this means that only a small volume will be magnetized by magnet 2 which reduces the amount of superconductor material needed for coils 14,16,18,20 which again reduces the weight and cost of magnet 2. Third, because coil/shield assemblies 8,22 are now operated at 50.degree. K., the amount of resistivity is down by a factor of about 20 from room temperature (300.degree. K.) which reduces the resistive input power and the amount of heat generated by a factor of 20 which, ultimately, reduces cooling cost and therefore the cost of operating magnet 2. Fourth, because the gradient coil assemblies 8 and 22 are operated in a vacuum, the acoustic noise created by the gradient coil is not conducted outside of vessel 4 which reduces the patient's discomfort associated with acoustic noise. Finally, the patient's claustrophobic fear associated with being in an enclosed environment is reduced by the short length of magnet 2.

Detailed Description Paragraph Table (1):
____________________________________ Thermal radiation form 300K 8.0 W Conduction down gradient supports 1.3 W Conduction down magnet supports 4.8 W Conduction from dual cryocooler interface 15.0 W Conduction down gradient power leads 9.6 W Conduction down main coil power leads 11.0 W Generation in the gradient coils at 50K 27.0 W Total 76.7 W ____________________________________

CLAIMS:

1. A refrigerated MR imaging magnet for reducing eddy currents, said magnet comprised of:

at least two gradient coil/thermal shield means located at a predetermined distance away from each other for substantially reducing eddy currents;

a magnet cartridge means having a coil form means and a coil means wound on said coil form means and substantially located radially between said gradient coil/thermal shield means for generating a substantially uniform magnetic field;

a refrigeration means operatively connected to said gradient coil/thermal shield means and said magnet cartridge means for refrigerating said gradient coil/thermal shield means and said magnet cartridge means;

a support means for supporting said gradient coil/thermal shield means and said magnet cartridge means;

a vacuum enclosure means which substantially encloses said gradient coil/thermal shield means and said magnet cartridge means;

a RF shield means rigidly attached to said vacuum enclosure means for substantially preventing a RF field from leaving said magnet;

a passive shim means substantially located adjacent to said vacuum enclosure means means for correcting said magnetic field; and

a RF coil means located at a predetermined distance away from said vacuum enclosure means for producing said RF field.

2. The magnet, according to claim 1, wherein said gradient coil/thermal shield means are further comprised of:

a fiber-reinforced epoxy material; and

a gradient coil set located substantially adjacent to said epoxy material.

3. he magnet, according to claim 1, wherein one of said gradient coil/thermal shield means is further comprised of:

a shield gradient coil; and

an outer thermal shield located substantially adjacent said shield gradient coil.

4. The magnet, according to claim 1, wherein one of said gradient coil/thermal shield means is further comprised of:

a main gradient coil; and

an inner thermal shield located substantially adjacent said main gradient coil.

5. The magnet, according to claim 1, wherein said vacuum enclosure means is further comprised of:

a vacuum-tight fiber-reinforced epoxy material.

6. The magnet, according to claim 1, wherein said coil means is further comprised of:

at least one superconducting winding means for generating a substantially uniform magnetic field.

7. The magnet, according to claim 1, wherein said enclosure means is further comprised of:

a metallic vacuum vessel means;

an end plate rigidly attached to said vessel means; and

a vacuum bore tube means located at a predetermined distance away from said vacuum vessel and operatively connected to said end plate.

8. The magnet, according to claim 1, wherein said at least two gradient coil/thermal shield means are rigidly and thermally attached by a first flange means for providing thermal stability for said magnet.

9. The magnet, according to claim 7, wherein said RF coil means is rigidly and thermally attached to said end plate by a second extension means for providing structural stability for said magnet.

10. The magnet, according to claim 7, wherein said end plate is further comprised of:

a cap means.

11. The magnet, according to claim 7, wherein said support means is further comprised of:

a first support means such that one of said at least two gradient coil/thermal shield means is operatively connected to said first support means; and

a second support means which is operatively connected to said magnet cartridge means.

12. The magnet, according to claim 11, wherein said first and second support means are rigidly attached to said end plate for providing structural stability for said magnet.

13. The magnet, according to claim 11, wherein said first support means is further comprised of:

at least four members located along one of said at least two gradient coil means at substantially 90.degree. from each said member for providing structural and thermal stability for said magnet.

14. The magnet according to claim 11, wherein said first support means is further comprised of:

a first support; and

a first mechanical support operatively connected to said first support.

15. The magnet, according to claim 11, wherein said second support means is further comprised of:

a second support; and

a second mechanical support operatively connected to said second support.

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L14: Entry 8 of 11 File: USPT May 8, 1990

DOCUMENT-IDENTIFIER: US 4924198 A
TITLE: Superconductive magnetic resonance magnet without cryogens

Abstract Text (1):
A superconductive magnet for magnetic resonance imaging not requiring consumable cryogens or requiring cryogen liquid or vapor cooling of superconducting coils is provided having a resin impregnated coil of superconductor wire. Heat conductive means having a thermal conductivity greater than the resin, contact the impregnated coil along the length of at least one of the impregnated coil surfaces. A thermal radiation shield is spaced away from and surrounds the resin impregnated coil and heat conductive means. An evacuable housing is spaced away from and surrounds the shield. The housing supports the shield, heat conductive means and the impregnated coil. A multiple stage cryocooler is mounted in the housing with one stage of the cryocooler thermally coupled to the radiation shield and with another stage capable of achieving lower temperatures than the stage coupled to the shield, thermally coupled to the heat conductive means, so that superconductive operation in a vacuum can occur without the coil being immersed in cryogen liquid or vapor.

Brief Summary Text (2):
The present invention is related to copending applications: Ceramic Superconductor Cryogenic Current Lead, Ser. No. 215,113; Cryocooler Cold Head Receptacle, Ser. No. 215,114; Efficient Thermal Joints For Connecting Current Leads to a Cryocooler, Ser. No. 215,131; Low Thermal Conductive Support for a Radiation Shield in a MR Magnet, Ser. No. 215,111; Cable Suspension System for Cylindrical Cryogenic Vessels, Ser. No. 215,479; and A Superconductive Quench Protected Magnet Coil, Ser. No. (RD-18,896).

Brief Summary Text (4):
The present invention relates to superconducting magnets used to generate a uniform magnetic field used in magnetic resonance diagnostics.

Brief Summary Text (5):
Present superconducting magnetic resonance magnets require cryogens to operate, either liquid helium or liquid helium and liquid nitrogen. Liquid helium is used in superconducting magnets not only for cooling but also to stabilize the magnet windings against motion induced instabilities. Cryogens evaporate and are lost during magnet operation and therefore require periodic cryogen delivery service and cryogen addition, with the attendant cryogen safety hazards. Furthermore, the use of cryogens complicate the cryostat construction since the cryogen containment vessels must be built in accordance with pressure vessel codes to withstand pressure surges as a result of magnet quenches or loss of vacuum in the vessel surrounding the cryogen containment vessel. The heavy cryostat containment vessel requires complicated supports and shields to position the cryostat containment vessel in the vacuum vessel and yet minimize heat conduction and radiation to the containment vessel from the ambient temperatures surrounding the vacuum vessel.

Brief Summary Text (6):
Helium leaks into the vacuum vessel surrounding the cryostat containment vessel are a common cause of failure in most superconducting magnets. Helium gas leaking into the vacuum vessel provides good heat conduction from the ambient temperature

surrounding the vacuum vessel to the cryogen containment vessel containing the superconducting coils.

Brief Summary Text (7):
Cryogen costs, specifically helium, are increasing and there is a limited supply which is economically recoverable. In many parts of the world helium is not available, therefore magnetic resonance imaging systems based on niobium titanium (NbTi) superconductors cannot be operated.

Brief Summary Text (8):
There is a broad demand for special purpose magnetic resonance imaging systems in doctor's offices and remote locations to address medical diagnosis in extremities, mamography, temporomandibular joints and small organs.

Brief Summary Text (9):
It is an object of the present invention to provide a superconducting magnetic resonance imaging magnet which does not require the use of consumable cryogens.

Brief Summary Text (10):
Another object of the present invention is to provide a superconducting magnetic resonance imaging magnet which has a reduced size, cost, weight, and increased reliability compared to the same field strength magnet presently available.

Brief Summary Text (11):
A further object of the present invention is to provide a superconducting magnetic resonance imaging magnet which does not require a helium vessel or nitrogen cooled thermal shield.

Brief Summary Text (12):
A still further object of the present invention is to provide a superconducting magnetic resonance imaging magnet which has a smaller diameter cylindrical superconducting winding compared to presently available superconducting magnets with the same field, thereby reducing the amount of superconductor required and reducing the magnet stored energy which has to be dissipated in a quench.

Brief Summary Text (13):
It is yet another object of the present invention to provide a superconductive magnetic resonance imaging magnet in which the patient's field of view is wide open and claustrophobic fears are not aggravated.

Brief Summary Text (15):
In one aspect of the present invention a superconductive magnet for magnetic resonance imaging not requiring consumable cryogens or requiring cryogen liquid or vapor cooling of superconducting coils is provided having a resin impregnated coil of superconductor wire. Heat conductive means having a thermal conductivity greater than the resin, contact the impregnated coil along the length of at least one of the impregnated coil surfaces. A thermal radiation shield is spaced away from and surrounds the resin impregnated coil and heat conductive means. An evacuable housing is spaced away from and surrounds the shield. The housing supports the shield, heat conductive means and the impregnated coil. A multiple stage cryocooler is mounted in the housing with one stage of the cryocooler thermally coupled to the radiation shield and with another stage capable of achieving lower temperatures than the stage coupled to the shield, thermally coupled to the heat conductive means, so that superconductive operation in a vacuum can occur without the coil being immersed in cryogen liquid or vapor.

Drawing Description Text (3):
FIG. 1 is an axonometric view of part of superconducting magnet partly in section;

Drawing Description Text (4):

FIG. 2 is an axonometric view of the copper connectors used to connect the superconductor coils of FIG. 1;

Drawing Description Text (5):
FIG. 3 is an axonometric view of the copper connection of FIG. 2 with the superconductor windings and overwrapping wire in place;

Drawing Description Text (7):
FIG. 5 is a partial end view partly in section of the magnet of FIG. 1 showing the radial cable suspension;

Drawing Description Text (8):
FIG. 6 is an isometric view partly in section of the magnet of FIG. 1 showing the axial cable suspension;

Drawing Description Text (9):
FIG. 7 is a partial sectional elevation view of the spacers used in supporting the radiation shield from the coil form;

Drawing Description Text (12):
FIG. 10 is an axonometric view of part of a superconducting magnet partly in section;

Drawing Description Text (13):
FIG. 11 is a partial end view partly in section of the magnet of FIG. 10;

Drawing Description Text (14):
FIG. 12 is a graph showing a magnet load line as a function of current and field strength at different operating temperatures;

Drawing Description Text (15):
FIG. 13 is an isometric view of an open hybrid magnet having resistive and superconductive coils;

Drawing Description Text (18):
FIG. 16 is an isometric view of another embodiment of a hybrid magnet;

Drawing Description Text (21):
FIG. 19 is a part sectional part exploded isometric view showing how the superconductive coils are wound in the magnet of FIG. 16;

Drawing Description Text (22):
FIG. 20 is a sectional isometric view of a compact open superconducting magnet;

Drawing Description Text (23):
FIG. 21 is a sectional isometric view of a compact open superconducting magnet;

Drawing Description Text (24):
FIG. 22 is an isometric view of an open hybrid magnet with a patient situated in the magnet bore;

Drawing Description Text (25):
FIG. 23 is an isometric view of an open hybrid magnet which is movable in the vertical direction and accommodates patients in a standing position;

Drawing Description Text (26):
FIG. 24 is a graph showing the first and section stage temperature of a cryocooler as a function of the heat loads imposed on the cryocooler;

Drawing Description Text (27):

FIG. 25 is a graph showing the temperature distribution in resistive current leads which have an optimized length over area ratio for a given current;

Drawing Description Text (28):
FIG. 26 is a cutaway isometric view of the cold end of a cryocooler having tapered superconductive ceramic leads between the first and section stages;

Drawing Description Text (29):
FIG. 27 is a cutaway isometric view of the cold end of a cryocooler with a tapered spiral superconductive current leads between the first and second stages; and

Drawing Description Text (30):
FIG. 28 is a side elevation view of the tapered spiral ceramic superconductive leads of FIG. 27.

Detailed Description Text (2):
Referring now to the drawing wherein like numerals indicate like elements throughout several embodiments of superconducting magnets without cryogens are shown. The magnets are designed to operate using a high temperature superconductor, namely niobium tin (Nb.sub.3 Sn) in the present embodiments. The magnets are directly cooled by a highly reliable two stage cryocooler, based on the Gifford McMahon cycle. In magnets of cylindrical shape operating at fields up to 1.5T, the magnet geometry is arranged for the lowest possible peak magnetic flux density within the superconductor. This requirement is dictated by the intrinsic field versus current capability of Nb.sub.3 Sn superconductor at elevated temperatures of 9.degree. K. or above. Peak fields much above about 4T cannot be accommodated with a reasonably high current density at 10.degree. K. To lower the winding peak field, the winding current density must be reduced by using more fiberglass insulation or co-winding a strand of stabilizer for improved quench propagation and winding hoop strength. Since long thin coil modules have lower peak field than short thick ones, the windings are spread axially to take the shape of a long thin solenoid in the embodiments of FIGS. 1 and 10.

Detailed Description Text (3):
Referring now to FIG. 1, a cylindrical magnetic resonance magnet 11 having an integral epoxy impregnated winding 13 in a shielded vacuum vessel 15 is shown. The six windings 17, 18, 29, 20, 21, and 22 are wound in slots symmetrically situated about the axial midplane of a cylindrical fiber reinforced form which in the present embodiment is a fiberglass form 25. Referring to FIGS. 1, 2, 3 and 4, the cylindrical fiberglass form 25 is fabricated as a uniform thickness shell and then machined to provide cutouts for copper connectors which have axially and circumferentially extending portions 31 and 27, respectively. The circumferential sections extend only partway around the coil form. Several lengths of superconductor wire can be soldered in a groove in the axial sections of the bus bar to reduce bus bar resistance during operation. Superconductive joints between niobium tin superconductors are difficult to be made. The copper connectors are used to join the six windings in series. The copper connectors are bonded to the fiberglass form 25 using epoxy. The fiberglass form is again machined with the copper connectors in place to provide six circumferentially extending winding slots with the circumferential portions of the connectors situated on either side of the slots. During the machining, ledges 33 are formed in the circumferentially extending copper connectors 27 at the bottom of the slot on one side and near the top of the slot on the other. A superconductor wire 35 which comprises niobium tin superconductors in a copper matrix and a strand of stabilizer 37, which comprises insulated copper wire in the present embodiment, are cowound in the slots. The Nb.sub.3 Sn and copper wires are soldered to the ledge on the copper connector in the bottom of the slot to begin the winding and wound in layers separated by woven glass cloth 41 as shown in FIG. 4. The superconductor wire and stabilizer are preferably soldered together at every layer of the winding. The insulation is removed from the stabilizer prior to soldering and the connection reinsulated using

tape, for example. The glass cloth is also used to line the slot prior to winding the coil also shown in FIG. 4. The windings in the slot terminate in a solder connection to the ledge 33 copper connector on the opposite side of the slot.

Detailed Description Text (4):
As shown in FIG. 4, distributed in the windings, every few layers, every third or fourth layer, for example, is a closed loop of copper foil 43. The copper foil is separated from the layer of windings above and below it by glass cloth insulation. The foil is overlapped and soldered so that it surrounds the winding, forming an electrically conductive loop. A portion of the loop is narrowed allowing the two wires being cowound to extend alongside the loop to begin the next layer. The number of closed loops of copper used in any winding is determined by several factors such as the amount of space available, the quench protected needed and cost. Axially extending copper connectors 31 couple adjacent circumferential copper connectors 27. Winding and terminating the superconductor in this fashion eliminates the need for any sharp angle turns at the beginning or end of each coil which could damage the superconductor wire. Co-winding with an insulated copper wire 35 controls the peak field and provides improved quench propagation. Filler pieces 45 situated above the copper connectors are bonded to the copper connectors by epoxy to provide a constant radius outer circumference diameter. The filler pieces can comprise G-10, for example. As shown in FIG. 3 the wound coils are overwrapped with stainless steel wire 47 to provide additional support against the Lorenz forces which act on the coils when the magnet is at full field.

Detailed Description Text (5):
A ring 51 of heat conductive material such as stainless steel is bolted to the ends of the coil form 25. The ring has a circumferential groove 53 which is aligned with axial slots in the fiberglass coil form shown in FIG. 4. The axial slots 55 extend the length of the coil form and are interconnected by circumferential slots 56 situated between windings on the form. A high heat conductivity nonmagnetic material such as copper is rolled around in the exterior of the coil form to form a shell 57 which can be seen in FIGS. 2 and 3. The shell is attached by overlapping and soldering the ends of the sheet together and by using high heat conductivity epoxy to secure the edges of the shell to the stainless steel rings 51. Electrolytic tough pitch (ETP) copper is preferred for use in the shell because of its high low-temperature thermal conductivity and a thermal contraction closely matching that of the fiberglass form 25. If an aluminum shell is used, the surface to be bonded to the fiberglass form is treated with a commercial chromate chemical-conversion coating, such as Alodine.RTM. 1200 S a trademark of Amchem Products, Inc. Ambler, Pa., or similar process such as sodium dichromate-sulfuric acid method, or chromic acid-sulfuric acid method, or alcohol-phosphoric acid method, or anodizing, to obtain good bonding to epoxy adhesives.. Surface roughening, such as sand blasting or knurling may also be employed to further enhance bonding. The preferred method of surface treatment for a copper shell is Ebonol.RTM. "C" special black cubric oxide coating, a trademark of Enthone, Inc., New Haven, Conn. Alternate methods include, ammonium persulfate process, or ferric chloride process, or hydrochloric acid-ferric chloride process, or sodium dichromate-sulfuric acid process.

Detailed Description Text (6):
Bus bars 61 and 63 are joined to the circumferential connectors 27 on either end of the coil form by soldering or using an indium pressure joint. The bus bars extend toward the midplane of coil on an insulator 64. The complete assembly of coils, coil form, rings and shell is vacuum impregnated with epoxy. The impregnation can take place with the assembly standing on end and the epoxy introduced at the lower end through a fitting in the ring 51 (not shown). The circumferential groove 53 in the ring 51 helps distribute the epoxy to all the axial channels 55 in the form. Additional circumferential grooves 56 help assure a good distribution of the epoxy throughout the interior of the windings and between the form 25 and the shell 57. After impregnation the magnet assembly is mounted inside the vacuum housing 15

surrounded by a radiation shield 65 which can be fabricated of copper or aluminum.

Detailed Description Text (7):
The bus bars in addition to carrying current between the coils provide a thermal bridge between the coils carrying heat generated during a quench from the interior of the resin impregnated coil to the adjacent coils increasing the speed at which the quench spreads to the other coils. The quicker the quench spreads the layer, the larger the area over which the magnet energy can be dissipated.

Detailed Description Text (8):
Referring now to FIGS. 1, 5 and 6, the coil form 25 is suspended in the shielded vacuum housing 15 by a radial and an axial cable suspension system. The radial suspension, which prevents radial movement of the coil form relative to the evacuable housing, has four cables 67, 68, 69 and 70 and eight cable tensioners arranged in pairs 73a and b, 75a and b, and 77 and b, and 79a and b. One cable tensioner which together with cable tensioner 79a makes up a pair of cable tensioners is not shown. In addition, one of the four pairs of cable tensioners are not shown. The cable tensioners are affixed to the exterior of the housing 15. At each end of the evacuable housing, two pair of cable tensioners are used with each pair of cable tensioners located circumferentially spaced on either side of where an imaginary diametral line passing through the end rings 51 emerges through the evacuable housing. Each cable is attached at one end to a respective one of the cable tensioners in each pair and each cable extends through an aperture in the housing, through shield 65 and more than half way around the ring in a respective one of the grooves 81 in the outer surface of the rings. Each cable then passes through an opening in the shield and the housing and is secured to the other cable tensioner in the pair.

Detailed Description Text (9):
The cables can comprise 1/4" stainless steel wire rope or a 1/4" aramid fiber cable. The cables terminate in a threaded rod 83 which is secured to the cable by, for example, a swagged fitting. The cable tensioners comprise machined steel cable anchor extension which are welded to the steel housing. The cable anchor exterior has two openings for receiving a pair of threaded rods at a predetermined angle. Belleville washers 85 and nuts 87 secure the cable end and maintain tension on the cables during cooling of the cables. Alternatively, a counterbored hole can be provided in the housing at an appropriate angle and the cable secured directly against the housing. An airtight cover 91 is welded in place over each pair of tensioners after magnet assembly so that the housing 15 remains airtight.

Detailed Description Text (10):
Referring now to FIG. 6 the axial coil form suspension is shown. To prevent axial motion of the coil form relative to the housing, four cables 93, 94, 95 and 96 each having one end formed in a loop have their looped ends encircling a respective one of four trunnions 97. The trunnions are located directly opposite one another with two trunnions on either side of the coil form. The trunnions on each side are symmetrically spaced axially about the axial midplane of the coil form and secured to the form. The trunnions are located close to the axial midplane to limit movement of the trunnions relative to the housing when the magnet is cooled and the coil form contracts. The cable looped about each trunnion extends axially away towards the closest end of the vacuum housing 15. To simplify adjustment during assembly, one or both ends of the cable turn radially outward about a pulley 101 mounted to the housing rather than extend through the housing ends. The cable extends radially through an aperture in the housing to securing means. The securing means comprises a tensioning bolt 103 about which the cable is wrapped and a "U-shaped" bracket 105 supporting the bolt from the housing. A nut and lock nut 107 are located on the tensioning bolt to prevent the bolt from turning relative to the bracket.

Detailed Description Text (11):

Referring now to FIGS. 5, 7 and 8, the shield 65 support is shown. Shield 65 is supported from the coil form by nine spacers affixed to the coil form and extending radially from the form. Six spacers 111 are arranged in two groups of three equally circumferentially spaced radially outwardly extending spacers.

Detailed Description Text (12):
The spacers 111 each comprise a thin wall G-10 cylinders with a disc shaped plug 113 on one end and a plug 114 having exposed threads on the other. The plugs which also can be fabricated from G-10 provide rigidity. Spacers 111 are situated in holes extending through the coil form 25 in heat conductive sleeves 115. The sleeves have a flanged end which is secured to the copper shell 57 of the coil form. The other end of the sleeve extends radially inward and has an inner threaded aperture to receive the threaded end of plug 114. The threaded disc shaped plug 114 has a slot 116 which extends to the spacer interior which serves to vent the spacer during evacuation of the magnet and to provide a screw driver slot to adjust the spacer radially outwardly from the form so that the end of the spacer having plug 113 extends beyond the coil form. Spacers 111 keep the radiation shield 65 surrounding the coil form spaced away and not directly touching any portion of the form or shell 57.

Detailed Description Text (13):
Referring now to FIGS. 5, 7 and 9, three spacers 117 extending from the interior of the coil form circumferentially spaced along the coil forms axial midplane 118, keep the portion of the radiation shield 65 situated in the interior of the coil form spaced away. Spacers 117 comprise a thin wall G-10 cylinder with a disc shaped plug 119 inserted at one end and a ring of insulating material 120 surrounding the other end. The ring 120 has threads on its outside diameter. The spacers 117 are located in apertures in the coil form. The shell end of apertures are threaded. The spacers 117 are threaded in place protruding radially inwardly from the coil form.

Detailed Description Text (14):
In addition to the nine radial spacers, four spacers 121, two on each axial end of the coil form are positioned in apertures to keep the ends of the shield from contacting the coil form. All the spacers 111, 117 and 121 by being situated in apertures and not contacting the coil form except at an end which is situated in the aperture, have a length greater than the distance between the coil form and the adjacent shield making the effective thermal path of the spacer greater than the distance between the coil form and the shield.

Detailed Description Text (15):
During assembly the vacuum pressure impregnated fiberglass coil form is placed inside the vacuum housing which has both ends removed. The four cables of the axial suspension system are looped around the trunnions. The radiation shield which comprises an inner and outer cylinder and two end rings has the outer cylinder slipped over the coil form which for assembly convenience can be standing on end inside the housing which is also on one end. Spacers 111 which are initially retracted almost flush with the coil form exterior are extended outwards using adjustment slots accessible from the interior of the coil form to adjust the spacing between the coil form and the outer cylinder of the radiation shield. Spacers 117 protrude a fixed distance radially inwards from the coil form are not adjustable after initial installation. Spacers 121 protrude from the ends of the coil form a fixed distance. Spacers 117 and 121 normally do not contact the shields but rather are a short distance away to ease assembly and reduce thermal conduction paths. If the magnet is jarred, such as during shipping, spacers 117 and 121 prevent contact between the shield and coil form. Typically peak shipping acceleration above gravity is 1 g in all directions. Since the magnet will be shipped with the coils superconducting, direct contact between shield and coil form should be avoided. With the axial suspension cables extending through the shield the shield end rings are bolted in place. Once the cable suspension are put in place and properly tensioned the ends of the shield can be bolted or welded in

place.

Detailed Description Text (16):
Even though spacers 117 and 121 act as bumpers to limit shield deflection spacers 111, 117 and 121 all must be designed for minimum heat leak in case of plastic deformation of the shield or out of roundness of the shield.

Detailed Description Text (17):
In a situation where the gap between magnet and shield is 3/8" and the coil form has a thickness of 1" the thermal path length can be increased by a factor of 3.7. While the thermal conduction length increases, the supports must be designed with possible buckling of the supports under their compressive load in mind. For the simplest straight tubular column design, a conservative estimate of the critical buckling load of a fiberglass epoxy cylinder 1 inch long with both ends clamped by disk shaped inserts may be given by using the free end model, which gives

Detailed Description Text (18):
Where Pcr is the critical load in pounds and t the radial thickness in inches. For a shield mass of 300 pounds, and for a 2 g total dynamic load carried by the minimum of 2 vertical supports, Pcr must be 300 pounds. Therefore the minimum tube thickness 0.0063". An adequate safety factor may be provided by a 0.010" thickness tube.

Detailed Description Text (19):
The heat leak down a 0.01" thickness by 5/8 inch diameter tube from 50.degree. K., the nominal shield operating temperature, to 10.degree. K. is 6 mW. The 11 supports thus represent a total heat load of 0.066 W, which corresponds to a negligible increase in magnet operating temperature of 0.03.degree. K. This heat leak must be carried to the cooler by the copper shell surrounding the coil form, so the outward radial supports are attached to a copper sleeve which carries their heat leak to the shell. The inner radial supports are threaded into the outer diameter of the coil form, so their heat will pass directly into the shell. The axial supports are threaded into the metallic end rings on the coil form, so their heat is also carried directly to the copper shell.

Detailed Description Text (20):
As shown in FIG. 1, a cryocooler 123 is positioned in a low field region in the midplane of the cylindrical assembly in a vertical service stack 125 which penetrates the outer vacuum vessel 15 and the thermal radiation shield 65. The second and first heat stations are in intimate contact with shell 57 and shield 65, to maintain the temperature below 10.degree. K. and 50.degree. K., respectively, by direct thermal conduction cooling. The bus bars are heat stationed to the second heat station. Permanently connected leads extend down the service stack and are heat stationed at both heat stations and electrically connected to the bus bars 61 and 63. A cryocooler cold head interface receptacle such as the one shown in copending application, Ser. No. 215,114 can be used in the embodiment of FIG. 1 and is hereby incorporated by reference.

Detailed Description Text (21):
Cryostat vacuum envelope 15 is shown designed as a passive magnetic shield to contain the fringe 5 Gauss field of a 0.5T magnet within a cylindrical surface of 3 m radius and 8 m length as typically required to install the magnet in a standard hospital room with a 12 foot high ceiling.

Detailed Description Text (22):
In one embodiment of a 0.5T magnet, the coils in FIG. 1 are wound with a bare Nb.sub.3 Sn wire having a 0.018 inch . diameter and an insulated copper wire also having a diameter of 0.018 inch. The interlayer glass cloth insulation is 0.004 inch and the current flowing in the conductors is 58 amperes.

Detailed Description Text (23):
With the shielded vacuum vessel the 5 gauss line is 2.9 m. in the radial direction measured from the center of the bore and 4.0 m. measured axially from the center of the bore. The inhomogeneity on the surface of 50 cm. diameter spherical volume centered in the bore is 65 ppm. and 15 ppm. on a 40 cm. diameter spherical volume centered in the bore.

Detailed Description Text (24):
Referring now to FIG. 10, superconductive magnet 131 with individually wound coils is shown. Three coil pairs 135 and 136, 137, 138, and 139 and 140 are co-wound with bare Nb.sub.3 Sn wire and a strand of stabilizer which comprises insulated copper wire in the embodiment of FIG. 10. The Nb.sub.3 Sn and copper wire are electrically connected at least at the beginning and end of each coil. The individually constructed coil windings with layers of insulation such as fiberglass cloth between layers are vacuum epoxy impregnated and all of the coils are made to have the same outside diameter by adjusting the fiberglass overwrap thickness on the outside of each superconductor coil. A closed loop of copper foil is used every few layers, every third or fourth, for example, to provide quench protection as described previously. The coils are assembled with cylindrical shell fiberglass spacers 143 to form a cylindrical subassembly with the coil pairs symmetrically situated in the axial direction about the midpoint of the cylindrical shell. The coil to coil lead connections are made in axially extending grooves (not shown) on the outside of the spacers using copper bus bars, for example. The cylindrical subassembly is machined to obtain a smooth cylindrical outside surface. The subassembly is adhesively bonded inside a high thermal conductivity thermal shell 145 fabricated from high thermal conductivity copper or aluminum which encloses the sides and inner diameter of the winding. Leads 147 and 149 extend from the windings at nearly the same circumferential location. The leads are electrically insulated from the high thermal conductivity shell. The coil subassembly, enclosed by the high thermal conductivity shell, is positioned in a thermal radiation shield 151 which is spaced away from the coil subassembly.

Detailed Description Text (25):
Referring now to FIG. 11 the coils in the thermal shell are suspended in a vacuum housing by a radial and axial cable suspension similar to the suspension used to support the coil form in FIG. 1. Stainless rings 153 with a single circumferential groove in the outside surface are bolted to the copper shell 145. Four cables 155, 156, (two cables not shown) and eight cable tensioners 161a and b and 163a and b, (four cable tensioners are not shown) are again used. The cable tensioners are positioned as previously described, however, the cables are connected differently. There are still two cables used at each end but each cable is connected between one of each of the pairs of cable tensioners that are closest circumferentially. Each cable extends less than halfway around the ring in the circumferential groove. The axial support is the same as previously described. The shield 151 is supported from the coil assembly at discrete locations as previously discussed.

Detailed Description Text (26):
A two stage Gifford McMahon cryocooler 123 is positioned in a low field region in the midplane of the cylindrical assembly in a vertical service stack 125 which penetrates the outer vacuum vessel 171 and the thermal radiation shield 151. The second stage of the cryocooler which operates at approximately 9.degree. K. is in intimate contact with the high thermal conductivity shell. The first stage of the cooler which operates at about 50.degree. K. is in intimate contact with the thermal radiation shield 151.

Detailed Description Text (27):
In one embodiment of the magnet shown in FIG. 11 with a 1.5T field in the magnet bore, the current through the magnet windings is 50 amperes. The superconductive coils comprise a bare Nb.sub.3 Sn wire with a diameter of 0.043 cm. cowound with an insulated copper wire also having a diameter of 0.043 cm. The bare Nb.sub.3 Sn wire

has a single core with 1500 filaments 5 microns in diameter. The copper to matrix ratio is 1.5. The wire can be obtained, for example, from Intermagnetics General Corp., Guilderland, N.Y. The interlayer insulation has a thickness of 0.010 cm. The magnet load line is shown in FIG. 12 for a Nb.sub.3 Sn wire diameter of 0.043 cm. The expected inhomogeneity is 29 ppm at the surface of a 50 cm. diameter spherical volume centered in the bore of the magnet and 4 ppm at the surface of a 40 cm. diameter spherical volume centered in the bore of the magnet.

Detailed Description Text (28):
A hybrid superconductive/resistive magnet 179 suitable for use in a magnetic resonance imaging system is shown in FIGS. 13, 14 and 15. Two epoxy-impregnated superconducting coils 181 and 183 are each supported by aluminum rings 185 which are shrunk fit on the outside surface of the epoxy-impregnated coils. The two coils are spaced apart from one another and lie in parallel planes with their centers being on a line extending perpendicularly to the planes. The aluminum rings 185 in addition to surrounding the outside surface of the coils cover the surfaces of the coils which face one another. The coils are spaced apart by four solid aluminum posts 187 which are secured between portions of the aluminum rigs covering the facing surfaces of the coils. The coils and posts are surrounded by a thermal shield 191 which surrounds each of the posts and coils individually. The coils and thermal shield are supported inside a vacuum enclosure 193 by three suspension posts 194. Each suspension post comprises two concentric G-10 thin wall tubes 195 and 197 to support the windings. The exterior of the tubes can be covered with aluminized mylar to reduce emissivity. One end of inner tube 195 is in contact with an aluminum bracket 201 affixed to the aluminum ring 185. The other end of the inner tube is supported in an aluminum cup 203 having a central aperture 205. The cup is also affixed to one end of the second concentric tube 197. The other end of the second concentric tube is suspended from a ring 207 which is supported by a third concentric tube 211 which surrounds the two concentric tubes 195 and 197. The third concentric tube 211 in addition to supporting the second concentric tube 197 also supports the thermal shield 191. The other end of the third concentric tube is affixed by a ring 213 to the vacuum housing 193 which also individually surrounds the three concentric tube supports. The inner and third tubes 195 and 211, respectively, in the supports are in compression while the second tube 197 is in tension. The suspension posts are sufficiently flexible to accommodate the radial thermal contraction of the shield and windings relative to the vacuum enclosure during cool down.

Detailed Description Text (29):
The vacuum enclosure housing 193 and radiation shield 191 are each fabricated as transversely split toroids. The radiation shields can have their exterior silver coated to reduce their thermal emissivity. The halves of the radiation shield can be joined together by soldering or by thermally conductive epoxy. The stainless steel housing has welded seams joining the halves to create an airtight enclosure.

Detailed Description Text (30):
The windings are cooled by a two-stage cryocooler 215 which is situated in an extension of the vacuum envelope. The first stage of the cryocooler is thermally connected to the thermal shield 191 to maintain the thermal shield at 50.degree. K. and the second stage is in thermal contact with the aluminum ring 185 of the winding to maintain the winding below 10.degree. K. Low thermal resistance is established between the cryocooler temperature stations and those of the shield and windings, by high pressure contact through soft indium gaskets.

Detailed Description Text (31):
Inboard resistive coils 217 are situated approximately in the same plane and concentric with each of the superconductive coils, respectively. The inboard resistive coils carry sufficient low ampere-turns so that they can be wound with hollow water cooled copper conductors to operate at a current density of 500 A/cm.sup.2. The resistive coils are each supported from the vacuum envelope by four

radially extending brackets 220. The resistive coils and superconductive coils are all connected in series and each carries current in the same circumferential direction. Current is provided to the superconductive coil by permanently connected heat stationed leads.

Detailed Description Text (32):
A 0.5T embodiment of the hybrid superconductive/resistive magnet would have the following characteristics. A spherical imaging volume of 20 cm. with a peak-to-peak inhomogeneity of 30 ppm. A patient access opening of 40.times.70 cm. The superconducting and resistive coils would each carry 50 amperes, with 6074 and 135 turns respectively, and a coil current density of 11,400 and 500 amperes/cm.sup.2, respectively. The superconductive coils each would have a radius of 59.4 cm. and the resistive coils would have a radius of 15.2 cm. The superconductive coils are spaced apart axially by 51.4 while the resistive coils are spaced apart by 52.2 cm. The cross section in height by width of the superconductive and resistive coils are 3.8.times.7 cm. and 3.7.times.3.7 cm., respectively. The magnet has an inductance of 206 H and stored energy of 258 kilojoules. The superconductor wire is Nb.sub.3 Sn wire and copper wire cowound. The bare Nb.sub.3 Sn wire and insulated copper wire each have a diameter of 0.043 cm. with a copper to superconductor ratio of 1.5. The superconductor wire is superconducting at 10.degree. K.

Detailed Description Text (33):
Referring now to FIGS. 16, 17, 18 and 19 another embodiment of a hybrid superconductive/resistive magnet is shown. The magnet 222 has generally the same configuration as the magnet of FIG. 13. Two superconducting coils 221 and 223 are provided wrapped around a copper coil form 225 having a "U" shaped cross-section. The coil form comprises three pieces, a band 227 formed by rolling and welding the ends of a copper strip and two circular flange pieces 229 having a central aperture which are joined at their inner diameter on either side of the band 227, such as by soldering. The superconductor wire can comprise a 0.017.times.0.025" Nb.sub.3 Sn superconductor with a copper to superconductor ratio of 0.5. The wire is covered by a 0.0025" glass braid. The wire is processed by the bronze method and is available from Oxford Airco.

Detailed Description Text (34):
The interior of the form is treated to improve bonding to epoxy and lined with fiberglass cloth. Referring particularly to FIG. 17, the wire is soldered to a starting terminal 231 in the flange 229 which is insulated from the rest of the flange by insulating block 233. The wire is wrapped with a tension of 3-5 ounces. Each layer is separated by fiberglass cloth insulation. Every fourth or fifth layer is surrounded by a thin copper foil band approximately 0.010 inch thick. The band surrounds the layer of wire in the coil form with the ends overlapping and soldered. The band allows the winding to pass through to the next layer as previously described. The winding terminates at finishing terminal 235 to which it is soldered. If splices are necessary, a 30" overlap of wire with the insulation removed can be soldered together with the resulting joint not being superconductive but having a very low resistance. The winding is covered with fiberglass cloth and copper plates 237 are slid into slots formed in the flange pieces. The slots extend to the periphery of the ring in one location to allow a plurality of copper plates to slide in and be positioned circumferentially about the perimeter of the winding. With the plates completely surrounding the winding an uninsulated stainless steel overwrapping 241 encloses the copper plates. The overwrapping is covered with release material and covered with brass shims (not shown) held in place by wire (not shown) and both coils 221 and 223 are vacuum epoxy impregnated. The wire and brass shims are removed together with any excess epoxy. After impregnation the plates are rigidly positioned in their slots. The copper plates transmit part of the radially outward load created by the windings during magnet operation to the "U" shaped coil form.

Detailed Description Text (35):

The coils are surrounded by a 50.degree. K. radiation shield 191 which in turn is surrounded by a vacuum enclosure housing 193. Both the shield and housing are fabricated as previously described, and supported in the cryostat by three supports 194 each having three concentric tubes 195, 197 and 211 also of the type previously described. Four aluminum posts 187 support coil 221 above coil 223. Clamping brackets 243 hold the coil form 225 and coils and are secured to supports and posts. The resistive coils are supported as previously described by brackets. Leads are permanently attached to the cryocooler connecting the two superconducting coils in series. The incoming leads are heat stationed to the two stages of the cryocooler. Leads from the second stage heat station are coupled to the input terminal of winding 223 and the output terminal of winding 221. The output and input terminal of windings 223 and 221, respectively, are coupled together. The resistance coils are also connected in series with each other and the superconductor coils. All the currents in all the coils flow in the same circumferential direction.

Detailed Description Text (36):
Another embodiment of an open magnet configuration is shown in FIG. 21. The magnet 244 has no resistive coils but rather has four superconducting resin impregnated coils, 251, 252, 253 and 254, two superconducting coils 251 and 252, and 253 and 254 in each of the two toroidal sections of the cryostat. Coil 251 and 253 have the same diameter and number of turns both of which are greater than those of coils 252 and 254 which both have the same diameter and number of turns. The superconductor coils in each of the toroidal sections is wound on a copper form 257. The coil forms are spaced apart parallel to one another with their centers lying on the same line which is perpendicular to the plane in which each of the coils lie. The coil forms are separated by aluminum posts as previously described with both coil forms supported by supports 194 each having three concentric tubes. A radiation shield surrounds the coil forms and is in turn surrounded by a vacuum enclosure. During operation, all the coils are connected in series with the coils 251 and 253 each carry current in the same direction while coils 252 and 254 carry current in the opposite circumferential direction.

Detailed Description Text (37):
In the magnet of FIG. 21, the coils 251, 252, 253 and 254 can be wound on a fiberglass form having the shape of the metal coil form 257. A conductive shell can supporting coils 253 and 254. The generally U-shaped shell fabricated of copper, for example, could be used as a pan in which the coils could be vacuum pressure impregnated.

Detailed Description Text (38):
In a 0.5T embodiment of FIG. 21, the outer coils are spaced 65 cm. from one another and have a radius of 56.1 cm. The outer coils carry 50 amperes in a Nb.sub.3 Sn wire having a diameter of 0.043 cm. which is cowound with an insulated copper wire having a diameter of 0.043 cm. The coils have a cross section 2.6 cm. high by 14 cm. in width. Superconductive coils 252 and 254 are spaced 51.8 cm. apart and have a radius of 40 cm. The coils 252 and 254 are cowound with the same dimension copper and Nb.sub.3 Sn wire and carry 50 amperes. Coils 252 and 254 each have a cross section of 2 cm. high by 3.4 cm. wide. The magnet has a clear bore diameter of 70 cm. with a transverse patient access of 40.times.70 cm. The calculated homogeneity in a 25 cm. sphere is 13 ppm.

Detailed Description Text (39):
As shown in FIGS. 22 and 23, the configuration of the open magnet 179 provides a greater patient field of view than magnets having a series of coils on a closed cylindrical coil form. The open magnets can be arranged with a patient 261 to be imaged standing or lying down. In the configuration of FIG. 23, the patient can remain stationary while the magnet moves in the vertical direction as needed.

Detailed Description Text (40):

A typical refrigeration capacity of a Model 1020 Cryodyne.RTM. cryocooler from CTI-Cryogenics, Waltham, Mass., operating from 60 Hz. power supply is shown in FIG. 24, which also shows the operating point of the cryocooler when used with the different embodiments superconductive magnets. The magnet cooling load is approximately as follows:

Detailed Description Text (41):
During start up the cryocooler is operating and a power supply ramps up gradually to a constant 50 amperes of current through the current leads. During ramp up, currents will be induced in the conductive loops in the layers of the coil. The currents, however, will not create a problem since the change of current is gradual. Once superconducting operation is achieved the power supply can remain connected, although the coils are superconducting the copper bars connecting coils have resistive losses as well as the current leads. The losses, however, are not very great and the large inductance and small resistance of the magnet provides for a large time constant.

Detailed Description Text (42):
During operation all heat carried to the magnet surface by radiation and conduction must be removed by the cryocooler so that the superconducting wire temperature does not increase above the transition temperature and cause a quench.

Detailed Description Text (43):
In case of a quench the conductive foil loops would begin to carry current induced in the loops due to the decreasing magnetic field. The loops would heat and spread the quench quickly to other coils. If the quench does not spread to the other coils quickly all the stored energy of the magnet would have to be dissipated at the original quench site, overheating and destroying the wire.

Detailed Description Text (44):
The cowound stabilizer if soldered to the superconductor every layer provides a low resistance in parallel with the portion of the superconductor wire undergoing the quench reducing the current carried by the quenched superconductor.

Detailed Description Text (45):
Current leads for the superconductive magnets in the embodiments of the present invention, cannot be helium vapor cooled to reduce conduction heat transfer to the superconducting magnet and to dissipate the resistance heating of the leads since consumable cryogens are not used. The current leads used are heat stationed to the first and second stage of the cryocooler to intercept heat before it reaches the superconducting coils.

Detailed Description Text (46):
In the cryocoolers used in the present invention resistive metallic conductors, such as copper, are used in the lead section from the exterior of the cryostat, which is at an ambient temperature of 300.degree. K., to the first stage of the cryocooler which has a temperature of 50.degree. K. during operation. A resistive metallic conductor is also used in the lead section from the first stage of the cryocooler which is at 50.degree. K. to the second stage which is at 10.degree. K. To minimize the conduction heat transfer to the heat stations by the current leads the lead aspect ratio must be optimized for a given current.

Detailed Description Text (47):
Since the resistance heating of the resistive metallic conductor is directly proportional to the length over cross sectional area, L/A, while conduction heat transfer to a lower temperature heat station is inversely proportional to L/A, there is an optimum L/A for which conduction heat transferred to the lower temperature station is at a minimum. For a resistive lead with nearly constant electrical resistivity along its length, the minimum heat transferred to the low temperature station is equal to one half the resistive heating of the lead section

plus the conduction heat transferred from the high temperature station. With the aspect ratio so adjusted, the net heat transferred from the high temperature station is zero since the other half of the resistive heating balances out the conduction heat transferred from that station. The temperature profile of the current leads with optimized aspect ratio for a 50 ampere current is shown in FIG. 25. The slope of the temperature profile of the leads extending between the 10.degree. K. and 50.degree. K. heat station as it approaches the 50.degree. K. heat station is seen to be horizontal signifying that the resistive and conductive heat flows are balanced. Similarly, the slope of the temperature profile of the current leads between the 50.degree. K. heat station and ambient as the lead approaches ambient temperature is horizontal.

Detailed Description Text (48):
If a high temperature ceramic superconductor is used in a lead section from the 50.degree. K. to 10.degree. K. heat station then the resistive heating in that lead section is zero and there is no optimum lead aspect ratio for that section. The ceramic superconductor lead section is made sufficiently large to carry the required current, I, and the lead length is made sufficiently long to result in acceptable conduction heat transfer to the 10.degree. K. heat station. Because of the strong decrease of the material critical current density, J.sub.c, with temperature T, the lead cross sectional area, A, must be varied inversely with temperature so that ##EQU1## with sufficient safety margin, (J.sub.c -J)/J.sub.c approximately 10 to 30 percent, where J is the actual current density in the ceramic lead and I is the current.

Detailed Description Text (49):
FIG. 26 shows a cold end portion of a cryocooler sleeve in an evacuated housing 260. Two straight ceramic leads 261 extending from the 50.degree. K. to 10.degree. K. stations 263 and 265, respectively, of a cryocooler sleeve with the leads tapered so that the lead has greater cross sectional area at the warmer end. The ceramic leads are heat stationed at the 50.degree. K. and 10.degree. K. heat stations 263 and 261, respectively. The high temperature section of the lead between the ambient (300.degree. K.) and the 50.degree. K. heat station comprises copper conductors having an optimized L/A to minimize the heat transferred to the 50.degree. K. station at the operating current. Generally, the leads should be metallized with silver. One method is sputtering another is using silver epoxy. The ceramic leads 261 are coated with silver loaded epoxy in the region where current conductive junctions are to be made. During processing of the ceramic, the epoxy is vaporized leaving behind a silver coating to which copper leads can be soldered. Resistive metallic conductors are soldered to the ceramic leads at the 10.degree. K. heat station using low resistivity solder, such as indium solder. The copper leads extending from the ambient are soldered to the ceramic leads in the vicinity of the 50.degree. K. heat station. The ceramic leads can be heat stationed, for example, using beryllia or alumina metallized with copper or nickel on both sides and soldered between the metallized ceramic lead and the cryocooler sleeve heat station. See copending application entitled, "Efficient Thermal Joints For Connecting Current Leads to a Cryocoller", incorporated herein by reference.

Detailed Description Text (50):
FIGS. 27 and 28 show two tapered spiral high temperature ceramic superconductive 271 and 273 which can be formed from a single cylindrical length of ceramic superconductor such as yttrium barium copper oxide (YBa.sub.2 Cu.sub.3 O.sub.x). The ceramic leads extends from the 50.degree. K. to 10.degree. K. heat station 163 and 165, respectively, and are heat stationed at the 50.degree. K. and 10.degree. K. heat stations. The ceramic leads are metallized with silver, such as by coating them with silver loaded epoxy which during heating leaves a coating of silver behind allowing the resistive metallic conductors to be soldered to the silver coated ceramic leads at the 10.degree. K. heat station. A low resistance solder such as indium solder is preferably used. The current leads each from ambient temperature are soldered to the ceramic leads in the vicinity of the 50.degree. K.

heat station.

Detailed Description Text (51):
Thus, the cryocooler in the sleeve which is thermally coupled to the magnet cryostat temperature stations at 10.degree. K., and 50.degree. K., will experience negligible heat load from the current leads at the 10.degree. K. station, when the optimized aspect ratio resistive metallic conductors or the ceramic superconductors are used. The cooling capacity at the 10.degree. K. station is limited and the heat station receives negligible heat load from the current leads, while the lead thermal load at the 50.degree. K. heat station can be easily handled by the increased refrigeration capacity available at this temperature.

Detailed Description Text (52):
Power is supplied to the magnets in the present invention by permanently connected leads supplied from a stable power supply. The power supply provides power lost due to the resistance in copper bus bars current leads and superconductor splices. To prevent arcing from occurring in case the leads become accidently disconnected or if a ceramic superconducting lead quenches, diodes are connected in the magnet to provide a continuous current path. During operation with the current leads connected and operating properly the voltage across the diodes is insufficient to cause them to conduct. If the leads current is interrupted, the voltage across the diode increases causing them to conduct.

Detailed Description Text (53):
Joints made in niobium tin superconductor wire are nonsuperconductive but have a very low resistance. Using only superconductive wire and no copper bus bars, or permanently connected leads, the magnet resistance would be approximately 10.sup.-8 ohms. The inductance of the magnet depends on magnet strength varying from 160 to 1600 henries for the embodiments shown. Once a current is established in the superconducting coils, the long time constant of the magnet circuit (thousands of years) could provide virtually persistent operation and a stable field in the magnet.

Detailed Description Paragraph Table (1):
Nb.sub.3 Sn Winding Radiation 0.110 Conduction 0.090 Current leads, copper 0.600 Cryocooler Second Stage Heat Load 0.800 Watts Radiation Shield Radiation 8.6 Conduction 2.0 Current leads, copper 4.8 Cryocooler First Stage Heat Load 15.4 Watts

Other Reference Publication (1):
J. E. Ostenson et al., "Performance of Nb.sub.3 Sn--Cu In Situ Conductor in a Superconducting Magnet", Advances In Cryogenic Engineering vol. 32 pp. 841-844 (1986), (ICMC Conference Aug. 12-16, 1985).

CLAIMS:

1. A magnet for magnetic resonance imaging not requiring consumable cryogens, cryogen liquid or vapor cooling of superconducting coils comprising;

a resin impregnated coil of superconductor wire;

heat conductive means, having a thermal conductivity greater than the resin, contacting the impregnated coil along the length of at least one of the impregnated coil surfaces;

a thermal radiation shield spaced away from and surrounding said resin impregnated coil and said heat conductive means;

an evacuable housing spaced away from and surrounding said shield, the housing supporting shield, heat conductive means and impregnated coil; and

a multiple stage cryocooler mounted in said housing, one stage thermally coupled to said radiation shield, another stage capable of achieving lower temperatures than the other stage thermally coupled to said heat conductive means, whereby said superconductor wire can operate superconductively without quenching in a vacuum without being immersed in cryogen liquid or vapor.

2. The magnet of claim 1 wherein said resin impregnated coil further comprises an overbanding to reduce hoop stress on the superconductive wire during operation.

3. The magnet of claim 1 wherein coils comprises a vacuum pressure impregnated coil.

4. An open magnetic resonance imaging magnet comprising:

a first and second resin impregnated circular coil of superconductor wire, said coils having the same diameter and number of turns;

a first and second heat conductive means, each having a thermal conductivity greater than said resin, contacting said first and second impregnated coils, respectively, along the length of at least one of each of the impregnated coil surfaces;

a plurality of thermally conductive support means, having a thermal conductivity greater than that of the resin, thermally coupling at discrete locations the heat conductive means on said first and second coil and spacing said coils apart parallel to one another with the geometric center of each coil lying on the same imaginary axial line;

a thermal radiation shield spaced away from and individually enclosing said first coil and said second coil and individually surrounding each of said support means;

an evacuable cryostat housing spaced away from and enclosing said radiation shield;

a two stage cryocooler mounted in said housing, the warmer stage thermally coupled to said radiation shield, the colder stage thermally coupled to said heat conductive means;

a plurality of bracket means; and

a third and fourth circular coil of current conducting wire, said third and fourth coils each having the same diameter and number of turns their diameter being less than the diameter of said first and second coils said third and fourth coils supported by said plurality of bracket means to be approximately in the same plane as the first and second coil, respectively, the geometric centers of said third and fourth coils lying on the same imaging axial line as the centers of the first and second coils.

5. The magnet of claim 4 wherein said heat conductive means comprises two nonmagnetic metal rings each having an "L" shaped cross section, one of said rings shrunk fit on the outside diameter of said first and second resin impregnated coils, respectively.

6. The magnet of claim 5 wherein said first and second coils are overbanded to reduce the hoop stress.

7. The magnet of claim 4 further comprising three concentric tubes of thermal insulating material said tubes situated inside said housing, the first tube surrounded by the second and the second surrounded by the third, the first tube

being joined to said second coil and extending through an aperture in said shield,

a first cap means for securing the other end of said first tube to one end of said second tube,,

a second cap means for securing the other end of said second tube and an end of said third tube, said second cap means secured to said shield, said other end of said third tube secured to said housing, said concentric tubes and first and second cap means supporting said first and second coils and said shield from said housing.

8. The magnet of claim 4 wherein said heat conductive means comprises two nonmagnetic metal coil forms around which said superconductor coils are wound.

9. The magnet of claim 8 wherein said superconductor coil is overbanded by high strength wire.

10. An open magnetic resonance imaging magnet comprising:

a first and second resin impregnated circular coils of superconductor wire, said coils having the same diameter and number of turns;

a third and fourth resin impregnated circular coils of superconductor wire, said coils having the same diameter and number of turns, said third and fourth coils having a smaller diameter than the first and second coils;

first and second heat conductive means, having a thermal conductivity greater than that of the resin, said first heat conductive means contacting the first and third resin impregnated coils along the length of at least one of each of the impregnated coils surfaces, said second heat conductive means contacting the second and fourth resin impregnated coils along the length of at least one of each of the impregnated coil surfaces;

a plurality of thermally conductive support means, having a thermal conductivity greater than that of the resin, thermally coupling at discrete locations the first and second heat conductive means and said plurality of support means spacing said first and second coils, as well as said third and fourth coils, apart and parallel to one another with the geometric centers of all the coils lying on the same imaginary axial line;

a thermal radiation shield spaced away from and enclosing said first and third coils and said first conduction means together and separately enclosing said second and fourth coils and said second conduction means ,together, said plurality of support means each individually enclosed;

an evacuable cryostat housing spaced away from and enclosing said radiation shield; and

a multistage cryocooler mounted in said housing, having a stage thermally coupled to said radiation shield and a stage capable of achieving lower temperatures than the other stage coupled to said second heat conductive means.

11. A superconducting magnetic resonance magnet comprising;

a hollow cylindrical fiber reinforced plastic coil form having circumferential slots on the outer surface and an axial slot joining said circumferential slots;

copper bus bars adhesively bonded in said axial slots;

superconductor wire wound in said circumferential slots soldered at the beginning

to the bus bars at one side and at the end to the bus bar at the other side;

overbanding enclosing the superconductor windings in the slots;

a conductive shell enclosing the exterior surface of said coil form;

resin impregnating the shield coil form interior, surrounding said windings with resin;

a radiation shield surrounding said coil form;

a vacuum housing enclosing said radiation shield;

suspension means supporting said coil form and radiation shield from said housing; and

a two stage cryocooler having a first stage thermally coupled to said shield and a second stage thermally coupled to said conductive shell.

12. The magnet of claim 11 wherein said bus bars have a circumferential portion which extend partway around said circumferential slot, said superconductor wire soldered to the circumferential portion of said bus bar.

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☐ 1. Document ID: US 20030218852 A1

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L17: Entry 1 of 13                    File: PGPB                    Nov 27, 2003

PGPUB-DOCUMENT-NUMBER: 20030218852
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20030218852 A1

TITLE: Magnetic condensing system for cryogenic engines

PUBLICATION-DATE: November 27, 2003

INVENTOR-INFORMATION:
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Minovitch, Michael Andrew         Los Angeles   CA      US

US-CL-CURRENT: 361/146
```

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Drawn De

☐ 2. Document ID: US 20030101732 A9

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L17: Entry 2 of 13                    File: PGPB                    Jun 5, 2003

PGPUB-DOCUMENT-NUMBER: 20030101732
PGPUB-FILING-TYPE: corrected
DOCUMENT-IDENTIFIER: US 20030101732 A9

TITLE: MINIATURE RECIPROCATING HEAT PUMPS AND ENGINES

PUBLICATION-DATE: June 5, 2003

INVENTOR-INFORMATION:
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Willen, Gary S.         Boulder     CO      US
Mohling, Robert A.      Boulder     CO      US

US-CL-CURRENT: 62/6; 60/520, 62/259.2
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Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Drawn De

3. Document ID: US 20020148237 A1

L17: Entry 3 of 13 File: PGPB Oct 17, 2002

PGPUB-DOCUMENT-NUMBER: 20020148237
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20020148237 A1

TITLE: Miniature reciprocating heat pumps and engines

PUBLICATION-DATE: October 17, 2002

INVENTOR-INFORMATION:

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US-CL-CURRENT: 62/6; 60/520, 62/259.2

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KMC | Draw. De

4. Document ID: US 6758046 B1

L17: Entry 4 of 13 File: USPT Jul 6, 2004

US-PAT-NO: 6758046
DOCUMENT-IDENTIFIER: US 6758046 B1

TITLE: Slush hydrogen production method and apparatus

DATE-ISSUED: July 6, 2004

INVENTOR-INFORMATION:

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Kral; Steven F.	Madison	WI		

US-CL-CURRENT: 62/3.1; 62/115, 62/123, 62/340, 62/345, 62/56, 62/914

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KMC | Draw. De

5. Document ID: US 6739137 B2

L17: Entry 5 of 13 File: USPT May 25, 2004

US-PAT-NO: 6739137
DOCUMENT-IDENTIFIER: US 6739137 B2

TITLE: Magnetic condensing system for cryogenic engines

DATE-ISSUED: May 25, 2004

INVENTOR-INFORMATION:

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US-CL-CURRENT: 62/3.1; 62/467

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw. De

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6. Document ID: US 6595006 B2

L17: Entry 6 of 13 File: USPT Jul 22, 2003

US-PAT-NO: 6595006
DOCUMENT-IDENTIFIER: US 6595006 B2
**** See image for Certificate of Correction ****

TITLE: Miniature reciprocating heat pumps and engines

DATE-ISSUED: July 22, 2003

INVENTOR-INFORMATION:

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US-CL-CURRENT: 62/6; 60/636, 62/3.1, 91/42

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw. De

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7. Document ID: US 6016659 A

L17: Entry 7 of 13 File: USPT Jan 25, 2000

US-PAT-NO: 6016659
DOCUMENT-IDENTIFIER: US 6016659 A

TITLE: Reactive thermo elastic cryostat

DATE-ISSUED: January 25, 2000

INVENTOR-INFORMATION:

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US-CL-CURRENT: 62/51.2; 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

8. Document ID: US 5735127 A

L17: Entry 8 of 13 File: USPT Apr 7, 1998

US-PAT-NO: 5735127
DOCUMENT-IDENTIFIER: US 5735127 A

TITLE: Cryogenic cooling apparatus with voltage isolation

DATE-ISSUED: April 7, 1998

INVENTOR-INFORMATION:

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US-CL-CURRENT: 62/6; 165/4, 174/125.1, 335/216, 62/259.2, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

9. Document ID: US RE33878 E

L17: Entry 9 of 13 File: USPT Apr 14, 1992

US-PAT-NO: RE33878
DOCUMENT-IDENTIFIER: US RE33878 E

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: April 14, 1992

INVENTOR-INFORMATION:

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Lessard; Philip A.	Boxborough	MA		

US-CL-CURRENT: 62/47.1; 165/133, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

10. Document ID: US 4795113 A

L17: Entry 10 of 13 File: USPT Jan 3, 1989

US-PAT-NO: 4795113
DOCUMENT-IDENTIFIER: US 4795113 A

TITLE: Electromagnetic transportation system for manned space travel

DATE-ISSUED: January 3, 1989

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Minovitch; Michael A.	Los Angeles	CA	90027	

US-CL-CURRENT: 244/63; 104/138.1, 104/282, 104/292, 244/158R, 244/172, 335/219

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Drawi De

11. Document ID: US 4766741 A

L17: Entry 11 of 13 File: USPT Aug 30, 1988

US-PAT-NO: 4766741
DOCUMENT-IDENTIFIER: US 4766741 A

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: August 30, 1988

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Acton	MA		
Lessard; Philip A.	Acton	MA		

US-CL-CURRENT: 62/51.2; 165/133, 62/47.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Drawi De

12. Document ID: US 4624109 A

L17: Entry 12 of 13 File: USPT Nov 25, 1986

US-PAT-NO: 4624109
DOCUMENT-IDENTIFIER: US 4624109 A

TITLE: Condensing atmospheric engine and method

DATE-ISSUED: November 25, 1986

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Minovitch; Michael A.	Los Angeles	CA	90027	

US-CL-CURRENT: 60/648; 60/655, 62/601, 62/615

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw D

☐ 13. Document ID: US 3364687 A

L17: Entry 13 of 13 File: USOC Jan 23, 1968

US-PAT-NO: 3364687
DOCUMENT-IDENTIFIER: US 3364687 A

TITLE: Helium heat transfer system

DATE-ISSUED: January 23, 1968

INVENTOR-NAME: KOLM HENRY H

US-CL-CURRENT: 62/608; 62/467

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw D

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Term	Documents
FREE	3059204
FREES	33266
WITHOUT	6455412
WITHOUTS	24
NO	11897407
NOES	1033
NOS	674473
NOE	7996
NONCRYOGEN$2	0
NONCRYOGEN	2
NONCRYOGENIC	102
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Search Results - Record(s) 1 through 7 of 7 returned.

1. Document ID: US 20030218852 A1

Using default format because multiple data bases are involved.

L18: Entry 1 of 7 File: PGPB Nov 27, 2003

PGPUB-DOCUMENT-NUMBER: 20030218852
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20030218852 A1

TITLE: Magnetic condensing system for cryogenic engines

PUBLICATION-DATE: November 27, 2003

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY	RULE-47
Minovitch, Michael Andrew	Los Angeles	CA	US	

US-CL-CURRENT: 361/146

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Drawu De

2. Document ID: US 6739137 B2

L18: Entry 2 of 7 File: USPT May 25, 2004

US-PAT-NO: 6739137
DOCUMENT-IDENTIFIER: US 6739137 B2

TITLE: Magnetic condensing system for cryogenic engines

DATE-ISSUED: May 25, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Minovitch; Michael Andrew	Los Angeles	CA	90027	

US-CL-CURRENT: 62/3.1; 62/467

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Drawu De

3. Document ID: US 5735127 A

L18: Entry 3 of 7 File: USPT Apr 7, 1998

US-PAT-NO: 5735127
DOCUMENT-IDENTIFIER: US 5735127 A

TITLE: Cryogenic cooling apparatus with voltage isolation

DATE-ISSUED: April 7, 1998

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Pfotenhauer; John M.	Madison	WI		
Lokken; Orrin D.	Fitchburg	WI		

US-CL-CURRENT: 62/6; 165/4, 174/125.1, 335/216, 62/259.2, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KMC | Draw De

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☐ 4. Document ID: US RE33878 E

L18: Entry 4 of 7 File: USPT Apr 14, 1992

US-PAT-NO: RE33878
DOCUMENT-IDENTIFIER: US RE33878 E

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: April 14, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Boxborough	MA		
Lessard; Philip A.	Boxborough	MA		

US-CL-CURRENT: 62/47.1; 165/133, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KMC | Draw De

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☐ 5. Document ID: US 4795113 A

L18: Entry 5 of 7 File: USPT Jan 3, 1989

US-PAT-NO: 4795113
DOCUMENT-IDENTIFIER: US 4795113 A

TITLE: Electromagnetic transportation system for manned space travel

DATE-ISSUED: January 3, 1989

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Minovitch; Michael A.	Los Angeles	CA	90027	

US-CL-CURRENT: 244/63; 104/138.1, 104/282, 104/292, 244/158R, 244/172, 335/219

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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☐ 6. Document ID: US 4766741 A

L18: Entry 6 of 7 File: USPT Aug 30, 1988

US-PAT-NO: 4766741
DOCUMENT-IDENTIFIER: US 4766741 A

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: August 30, 1988

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Acton	MA		
Lessard; Philip A.	Acton	MA		

US-CL-CURRENT: 62/51.2; 165/133, 62/47.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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☐ 7. Document ID: US 4624109 A

L18: Entry 7 of 7 File: USPT Nov 25, 1986

US-PAT-NO: 4624109
DOCUMENT-IDENTIFIER: US 4624109 A

TITLE: Condensing atmospheric engine and method

DATE-ISSUED: November 25, 1986

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Minovitch; Michael A.	Los Angeles	CA	90027	

US-CL-CURRENT: 60/648; 60/655, 62/601, 62/615

Full | Title | Citation | Front | Review | Classification | Date | Reference | Claims | KWIC | Draw De

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Term	Documents
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(L17 AND (GRADIENT)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	7

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1. Document ID: US RE33878 E

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L19: Entry 1 of 2 File: USPT Apr 14, 1992

US-PAT-NO: RE33878
DOCUMENT-IDENTIFIER: US RE33878 E

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: April 14, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Boxborough	MA		
Lessard; Philip A.	Boxborough	MA		

US-CL-CURRENT: 62/47.1; 165/133, 62/51.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

2. Document ID: US 4766741 A

L19: Entry 2 of 2 File: USPT Aug 30, 1988

US-PAT-NO: 4766741
DOCUMENT-IDENTIFIER: US 4766741 A

TITLE: Cryogenic recondenser with remote cold box

DATE-ISSUED: August 30, 1988

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bartlett; Allen J.	Milford	MA		
Andeen; Bruce R.	Acton	MA		
Lessard; Philip A.	Acton	MA		

US-CL-CURRENT: 62/51.2; 165/133, 62/47.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KMC | Draw De

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Term	Documents
MAGNETIC	1427723
MAGNETICS	12351
RESONANCE	280011
RESONANCES	16254
MRI	24243
MRIS	329
NMR	137006
NMRS	235
(18 AND (MRI OR (MAGNETIC ADJ RESONANCE) OR NMR)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	2
(L18 AND ((MAGNETIC ADJ RESONANCE) OR MRI OR NMR)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	2

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